# Terrestrial Information Systems

Research conducted in Terrestrial Information Systems focused on the following areas:

(1) Developing reliable low-cost computing systems for the production, distribution and analysis of regional and global data sets,

(2) Improving the security and reliability of the Laboratory's computing environment and

(3) Investigating the utility of remotely sensed data for studying tropical diseases.

Producing global data products for the MODIS (MODerate-resolution Imaging Spectroradiometer) instrument, which flies on the Earth Observing System (EOS) Terra and Aqua spacecraft, drives the research in the area of high throughput processing. By 2004, the Laboratory's MODIS data processing system will produce and distribute over 4 Terabytes (TB) of global science products each day. Producing this volume of daily products has led to the development of systems, which combines such diverse technologies as Storage Area Networks (SAN), large supercomputers and clusters of low-cost personal computers. Developing the data processing system for the Ozone Measuring Instrument (OMI), which will be launched on the EOS Aura spacecraft in 2004, provides an opportunity to explore reuse of components from the MODIS processing systems as a means of reducing cost, meeting schedule and improving reliability. The Crustal Dynamics Data and Information System (CDDIS) serves as NASA's archive for space geodesy data sets shipping products to over 150 users per day. Since 1982 the CDDIS has focused on developing and operating a low-cost, highly reliable data archive with the flexibility to add data sets and data services to meet the needs of the international science community. The need to achieve high reliability for the above missions has spurred work in automating software updates and configuration management, automated monitoring of systems and improvements in intrusion prevention and detection. These have simplified the job of managing the information technology infrastructure of the Laboratory and improved the security of its computing systems. An outgrowth of the Branch's work in global data processing has been efforts in the area of quality assessment and validation of global products and regional applications of remote sensing to study diseases spread by mosquitoes and sand flies in South America and Thailand.

### *Global data processing for MODIS*

MODIS (MODerate-resolution Imaging Spectroradiometer), launched on the EOS Terra spacecraft in December 1999, images the Earth in 36 spectral bands in visible through thermal wavelengths (459nm – 9.58μm) with spatial resolution of 250m, 500m and 1 kilometer. From an initial 70GB of raw instrument data, 44 global science products are produced with an average daily volume of 760GB. These products extend the data record of products from heritage sensors, such as land surface reflectance, sea surface temperature and NDVI from AVHRR and ocean color from SeaWiFS, and offer finer spatial resolution, better calibration and more precise Earth-location of pixels.

In 2001, the focus of the MODIS science team and its data processing support team was to get MODIS products to a level of maturity where they could be used in quantitative studies of global change. In reaching this goal, over 400 changes were made to the science software to generate improved science products or speed up processing. In July of 2001, all 44 MODIS products reached the desired level of quality and a reprocessing for the period November 2000 through December 2001 began.

By the end of 2001, the MODIS Adaptive Processing System (MODAPS) routinely produced and distributed 3 days of science products each day, a volume of approximately 1.2TB, and had produced 12 months of MODIS products with improved science algorithms developed for this reprocessing effort.

**Figure 1. The Blue Marble**

Dr. Fritz Hasler, Dr. Reto Stockli and David Herring used MODIS land surface reflectance products from 2001 to produce an image of the Earth as seen from space that can be downloaded from http://earthobservatory.nasa.gov/Newsroom/BlueMarble/ . (Figure 1)

To meet the MODIS Science Team's need for rapid processing of MODIS data, the MODAPS production systems reads and writes billions of bytes of data per second and produces, archives and distributes tens of thousands of MODIS data products each day. This level of processing is achieved through a combination of Silicon Graphics Inc. (SGI) supercomputers attached to Storage Area Networks of Fibre Channel disks for high speed data transfer and hundreds of personal computers with Intel Pentium III processors connected to the supercomputers to achieve high computation rates. Software development continues on the MODAPS with the goals of enabling it to scale to 10TB/day of MODIS production while generalizing the processing framework to support its reuse in future projects which also are focused on producing a long time series of global products.

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### *The MODIS Land Data Operational Product Evaluation (LDOPE) Facility*

Quality assessment (QA) is an integral part of the MODIS Land (MODLAND) product production chain and focuses on evaluating and documenting the scientific quality of the products with respect to their intended performance. The MODIS Land Data Operational Product Evaluation (LDOPE) facility was formed in Code 922 prior to MODIS launch to support the MODLAND science team and to provide a coordination mechanism for MODLAND's QA activities. The LDOPE is staffed by a small group of scientific and technical personnel and is located in close physical proximity to the MODAPS to enable efficient communication with the production managers and to ensure rapid data access. The LDOPE personnel assume routine QA of the MODLAND products, track the quality of non-MODLAND input products (e.g., the MODIS calibrated radiances and cloud mask products), check for error propagation through interdependent MODLAND products, develop and maintain QA tools, databases and procedures, disseminate QA results and information within the Science Team, and ensure that the MODLAND QA results are available to the public.

In 2001 the LDOPE has continued to assess the quality of the MODLAND products, leading directly to product algorithm refinements and improved product performance. The LDOPE has continued to document the quality of the MODLAND products by populating publicly accessible web sites that define the MODLAND product Science Quality metadata and document known problems with each product.

The LDOPE staff has developed semi-automated QA procedures and time series analysis techniques. The important goal of this work is to enable the LDOPE staff to assess the potentially tenfold increase in data volume anticipated as a result of simultaneous product reprocessing and production of MODLAND products from the Terra and Aqua data streams.

Web sites: http://landdb1.nascom.nasa.gov/QA_WWW/release.cgi and

http://landdb1.nascom.nasa.gov/QA_WWW/issues.html

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### *Ozone Measuring Instrument (OMI)*

A 30 year record of consistent global observations of the Ozone layer is expected once the Ozone Measuring Instrument (OMI) results are combined with those from NASA's ongoing Total Ozone Measuring Spectrometer (TOMS) data. Provided by the Netherlands Agency for Aerospace Programmes (NIVR), OMI will fly on the EOS Aura mission in 2004. Algorithm development for OMI is the responsibility of a joint European-U.S. Science Team. The U.S scientists on this team have been producing global total ozone column measurements for the last 24 years starting with the launch of the TOMS on Nimbus 7 in 1978. The Atmospheric Chemistry and Dynamics Branch of the Laboratory for Atmospheres partnered with the Terrestrial Information Systems Branch to implement the system for producing the OMI data. The OMI Science Investigators Processing System, OSIPS, is directly based on the MODIS Adaptive Processing System currently processing massive amounts of MODIS data. Key features of OSIPS are its quick availability and its use of commodity hardware to provide very high processing ability at low cost. The system design allows the implementation in an evolutionary manner, adding new hardware in a series of builds obtaining increasing capacity on a just in time basis as the mission approaches launch. This makes it possible to benefit from the constantly increasing performance per dollar that is a hallmark of the computer industry. The Terrestrial Information Systems Branch's expertise with this form of development, together with our knowledge and experience with implementing algorithms to comply with the requirements of NASA's EOS Data and Information System has enabled the U.S. Team to meet a very demanding schedule for algorithm delivery despite its late addition to the Aura Mission.

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## *Crustal Dynamics Data Information System (CDDIS)*

The CDDIS is a dedicated data center supporting the international scientific community as NASA's space geodesy data archive since 1982. This data archive was initially conceived to support NASA's Crustal Dynamics Project; since the end of this successful program in 1991, the CDDIS has continued to support the science community through an RTOP from NASA's Solid Earth and Natural Hazards program, HQ Code YS. The CDDIS provides easy and ready access to a variety of data sets, products, and information about these data. The CDDIS archive includes Global Positioning System (GPS), GLObal NAvigation Satellite System (GLONASS), Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), and Doppler Orbitography and Radiolocation Integrated by Satellite (DORIS) data and products. The specialized nature of the CDDIS lends itself well to enhancement to accommodate diverse data sets and user requirements.

The CDDIS serves as one of the primary data centers for the following services within the International Association of Geodesy (IAG):

International GPS Service (IGS) and its diverse pilot projects and working groups

International Laser Ranging Service (ILRS)

International VLBI Service for Geodesy and Astrometry (IVS)

International Earth Rotation Service (IERS)

International DORIS Service (IDS)

The CDDIS operated in the Laboratory for Terrestrial Physics Computing Facility located in Building 33 at NASA GSFC. This computer facility hosts web sites for the CDDIS, the ILRS, and several other GSFC facilities. The majority of the CDDIS data holdings are accessible through anonymous ftp and the web.

As in past years, the year 2001 saw another increase in the usage of the CDDIS. On average, 2.2M files totaling over 250 Gbytes in size were downloaded from the CDDIS archive each month. Furthermore, over 150 users accessed the CDDIS on a daily basis to download data. Nearly ninety countries accessed and downloaded data from the CDDIS last year. Over 120 institutions in over sixty countries supply data to the CDDIS on a daily basis for archival and distribution to the international user community.

Information about the system is available at http://cddisa.gsfc.nasa.gov.

### Interdisciplinary Uses of CDDIS Data

The majority of CDDIS data sets are utilized for geodetic analysis, such as plate tectonics, earthquake displacements, seismisity studies, volcano monitoring, Earth orientation, atmospheric angular momentum, etc. This archive of GPS, SLR, VLBI, DORIS, and GLONASS data are utilized to precisely determine station positions and velocities of the network stations and thus are used to maintain the terrestrial reference frame, the set of points which realize an ideal reference system. As a consequence, user data from single points or dense regional networks can be tied to this global reference frame.

The IGS and ILRS have been generating precise satellite ephemerides on a routine basis for many years. Precise orbits available from the CDDIS for GPS satellites have accuracy of 5 cm. SLR and DORIS data retrieved from the CDDIS archive are utilized in precise orbit determination (POD) efforts for several international oceanography missions, including TOPEX/Poseidon, ERS-1/2; in the near future, JASON and ENVISAT will join this list of missions deriving precise orbits from SLR and/or DORIS data. GPS flight receiver data, as well as SLR data, are also utilized for POD efforts for international geophysical missions such as GFO-1 and CHAMP and the future GRACE and ICESat missions.

The GPS network within the IGS consists of globally distributed, continuously operating stations with dual-frequency P-code receivers. By using these two frequencies, the effects of the ionosphere can be determined and used to correct positional measurements. Current ionosphere products derived from GPS data and available through the CDDIS include the vertical total electron content (TEC). The TEC product can be used in the calibration of altimeter data and to correct single frequency GPS data. In 2001, a special campaign was conducted by the IGS to study the effects of the solar maximum on the ionosphere, particularly in the polar and equatorial regions. High-rate data from the global GPS network were archived at the CDDIS for a one-week period during April in support of this activity.

The GPS signal is sensitive to the refractive index of the atmosphere, which is a function of pressure, temperature, and moisture. Both space- and ground-based GPS meteorology can contribute to global climate research. Troposphere products generated by IGS analysis centers include precipitable water vapor, derived from zenith path delays. The results are dependent upon meteorological sensors collocated at the GPS sites, and can be a valuable tool in the validation of other meteorological products.

**New Thrusts for the CDDIS**

In 1999, the IGS issued a Call for Participation in the Low Earth Orbiters (LEO) Pilot Project; this activity started in the spring of 2001. The CDDIS has established procedures to retrieve, reformat, archive and provide access to data from a ground network of approximately forty low-latency GPS receivers operating at a one-second sampling rate. In 2002, the CDDIS will begin the archive of data from GPS flight receivers on board several low-Earth orbiting satellites. Analysts will retrieve these data to produce precise orbits of these LEO platforms, which will aid in the generation of other products, such as temperature and water vapor profiles in the neutral atmosphere and ionosphere imaging products. The IGS LEO Pilot Project will test the ability of the various components of the IGS infrastructure to support near real-time acquisition, dissemination, and processing of GPS data.

The CDDIS will begin support of another IGS Pilot Project in 2002, the GPS Tide Gauge Benchmark Monitoring Pilot Project (TIGA-PP). The CDDIS submitted a successful proposal to serve as an archive for data from continuously-operated GPS receivers located at or near tide gauge instruments. The pilot project aims to establish and maintain new geodetic ties to tide gauge systems to aid in climate change studies. The primary product of the analysis will be a time series of coordinates for analyzing vertical motions of tide gauges and tide gauge benchmarks. The realization of the scientific objectives of the pilot project will aid scientific research in many areas, particularly NASA research in geodesy and geophysics within the Solid Earth and Natural Hazards program and altimetry and sea level research programs.

Efforts are also underway to increase the size of the on-line archive of the CDDIS. A 600-platter CD-ROM jukebox will provide access to the archive of older GPS data. The CDDIS computer facility will also be augmented with a second 500 Gbyte RAID disk array as well as a dedicated tape backup system.

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*MODIS Rapid Response System*

The unique combination of spatial resolution, areal coverage and spectral characteristics of MODIS makes the instrument ideal to observe a variety of rapid events: active fires, floods, smoke transport, dust storms, severe storms, volcanic eruptions. A new processing system - called the MODIS Rapid Response System - has been developed in the Branch to provide a rapid response to those events, with initial emphasis on active fire detection and quasi-true-color 250m-resolution imagery (see Figure 2). MODIS data of most of the Earth's land surface is processed within a few hours of data acquisition. A basic atmospheric correction is performed operationally to provide true-color imagery. An operational detection process retrieves the location of active fires. The perimeter of the fires are overlaid on true-color imagery and posted on a web site.

A collaboration between NASA, the University of Maryland and the USDA Forest Service has been developed to provide fire information derived from MODIS to the fire managers. Active fire locations detected by MODIS in the conterminous United States and Alaska are produced by the Rapid Response System and communicated to the USDA Forest Service within a few minutes of production.

These active fire locations are used to generate regional fire maps, updated daily and provided to the fire managers to help them allocate adequate resources to fire fighters. Active fire locations are also distributed to the Global Observation of Forest Cover (GOFC) user community through a web interface integrating MODIS active fire locations and Geographic Information System (GIS) datasets. Burn severity maps derived from MODIS Rapid Response data are being developed to help the Forest Service Burned Area Emergency Rehabilitation teams. A smoke index is also being developed to support smoke dispersion analyses.

The Rapid Response initiative and the collaboration with the Forest Service have been a great success. The capabilities of the system were particularly demonstrated during the 2001 fire season in Western United States. The Rapid Response Project received significant media coverage from TV, radio and print press: e.g., CNN, ABC7/WJLA, MSNBC, FOX5, CBS/WJZ, the New York Times, the Washington Post, the Baltimore Sun, Federal Computer Week, and 40 stations that ran the NASA-TV video file.

A mechanism has been developed to expedite the process of providing images to the Earth Observatory, the Visible Earth, the MODIS Home page, and the Science Visualization Studio for use in public outreach. This year 70 images from the Rapid Response System have been posted as image of the day on the Earth Observatory and more than 500 images have been sent to the Visible Earth database.

A significant effort is being made to package the codes developed to generate the Rapid Response products and make those available to the MODIS Direct Broadcast community. This transition to Direct Broadcast was prototyped in December 2001 with the Forest Service Remote Sensing Applications Center in Salt Lake City, which is now able to process MODIS data from their own dish and generate the Rapid Response products over Western United States within minutes of data acquisition. Collaboration with the Direct Readout Lab at NASA/GSFC has been initiated to coordinate the software release.

The Rapid Response System has been recently identified as a potential contributor to the current national defense effort. The Air Force Weather Agency has been given access to MODIS Rapid Response imagery. New capabilities are being developed to accommodate AFWA's requirements. In particular, the capability of automatically generating high-resolution subsets of specific areas within minutes after the MODIS input data is received.

**Figure 2. Corrected Reflectance product from the Rapid Response system showing fires in Siberia on May 22, 2001.**

Web sites: http://rapidfire.sci.gsfc.nasa.gov  and  http://rapidresponse.umd.edu

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### *MODIS Validation - EOS Land Validation Core Sites*

Lessons learned from the previous generation of global land imaging systems indicate that validation is critical for accurate and credible product usage (Justice and Townshend, 1994).  For each product derived from satellite data there needs to be some field data, or ground reference, to ensure that the information in the satellite product is truly representative of ground level processes.  To facilitate validation of its global products by establishing a network of ground reference information, the MODIS land team has led the development of the EOS Land Validation Core Sites.

Following a number of years of consensus building among the EOS instrument teams, it was decided to focus land validation activity on a set of "Core" sites (Justice et al., 1998b).  This focus allows collaboration within and among science teams and reduces the duplicated effort that would result from validation efforts at disparate sites.  This decision resulted in an EOS community effort to establish the EOS Land Validation Core Sites (Morisette et al., 1999), see Figure 3.  The sites were chosen to cover a range of biophysical and climatological conditions within the practical constraint of utilizing existing or planned activities and infrastructure.

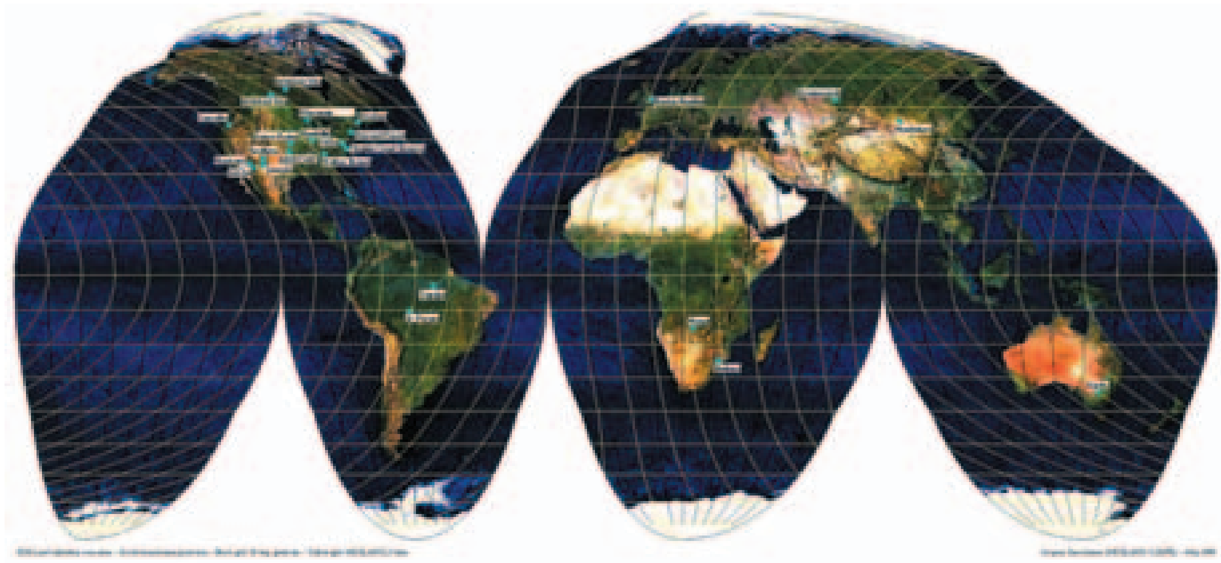

**Figure 3. EOS Land Validation Core Sites**

The EOS Land Validation Core Sites are providing the user community with timely ground, aircraft, and satellite data for EOS science and validation investigations. The Core Sites are intended to provide the general community with some of the best and simplest opportunities for early multi-sensor data comparisons and synergistic science. The sites typically have a history of in situ and remote observations and can expect continued monitoring and land cover research activities. Many Core Sites have towers equipped with above-canopy instrumentation for near-continuous sampling of landscape radiometric, energy and $CO_2$ flux, meteorological variables, and atmospheric aerosol and water vapor. These measurements are complemented by intensive field measurement campaigns. Inter-sensor comparison and data continuity (Cihlar et al., 1997) are facilitated by overlapping operations of different sensors and collecting imagery from as many applicable sensors as possible. The Core Site philosophy has been to collect, archive, and distribute as much field data and EOS satellite and airborne imagery as possible. Core Sites are intended to serve as magnets for ground-based data collection and remote sensing research.

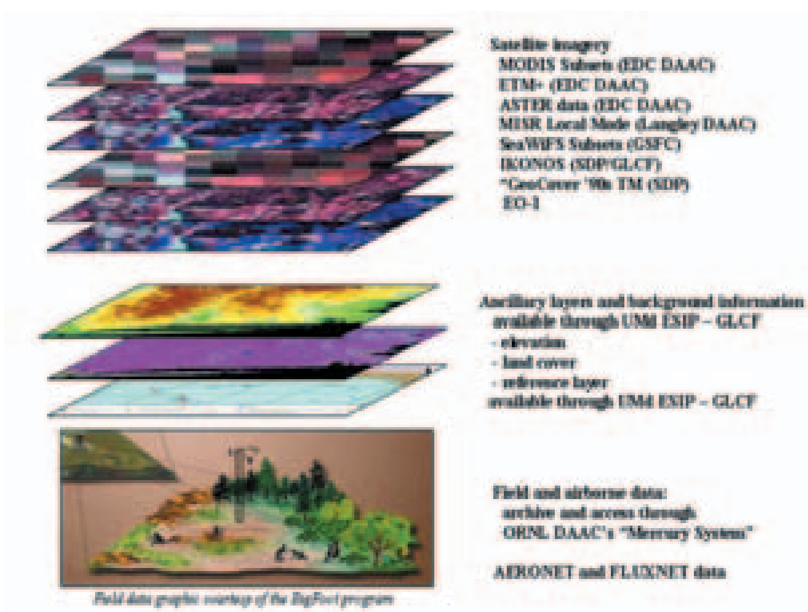


**Figure 4. Data sets collected at EOS Core sites for product validation.**

The entire data suite being compiled for the Core Sites is depicted in Figure 4. All data available for the Core Sites are accessible through the Internet. Access limitation applies to IKONOS data, which is only available to registered Scientific Data Purchase (SDP) users. Registration with SDP is limited to research affiliated with NASA.

**Recent activity and future plans**

EOS satellite data over the Core Sites continued to be tasked, ordered and staged throughout 2001. All Core Sites experienced field, tower, or airborne data collection activity in 2001. The infrastructure established in 2000 provided a mechanism to share and distribute the various data sets. User statistics from Oak Ridge National Lab (ONRL) and EDC DAAC indicate there is continued and growing interest in these data sets throughout the validation community. The Core Sites will also serve as primary sites for land-related validation activities in the Aqua time frame.

Although their development was primarily for validation of EOS data, the Core Site infrastructure can be used for validation of all satellite sensors (Justice et al, 2000). In 2001, the Committee on Earth Observing Satellites (CEOS), a working group on calibration and validation started exploring the establishment of a set of "CEOS Land Validation Core Sites", using the EOS Land Validation Core Sites as a foundation. Also, the National Polar-orbiting Operational Environmental Satellite System Preparatory Project (NPOESS NPP) has included the EOS Land Validation Core Sites into their validation plans as primary targets for land product validation.

This is a joint activity between the Terrestrial Information Systems and Biospherics Sciences Branches, funded and coordinated through the MODIS Land Team Validation budget, with support from MODAPS, other EOS teams, and EDC and ORNL DAACS.

References:

Cihlar, J., Chen, J. and Li, Z., 1997. On the Validation of Satellite-derived Products for Land Applications. Canadian Journal of Remote Sensing. 23(4):381-389.

Justice, C.O. and Townshend, J.R.G. 1994. Data sets for global remote sensing: lessons learnt. International Journal of Remote Sensing. 15(17):3621-3639.

Justice, C., Belward, A., Morisette, J., Lewis, P., Privette, J. and Baret, F., 2000. Developments in the 'validation' of satellite sensor products for the study of land surface. International Journal of Remote Sensing. 21(17):3383-3390.

Morisette J., Privette, J.L., Justice, C.O., Olson, D., Dwyer, J., Davis, P., Starr, D. and Wickland, D., 1999. The EOS land Validation Core Sites: background information and current status. The Earth Observer, 11(6):21-25.

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### *Geographical Information Systems (GIS) Studies of Vector-borne Disease*

Geographical information systems can be used to elucidate the spatial relationships between environmental variables and cases of disease. Environmental variables such as the presence or absence of wetlands, the weather, the type of surrounding vegetation, elevation, and so forth can be mapped using remotely sensed data. Some of the environmental variables that control vector-borne diseases are still not well understood. For instance, different vector species prefer different breeding habitats. Some mosquito species breed in river environments, some in cattail marshes. Some mosquito species are more efficient vectors of malaria than others.

By analyzing the spatial relationships between the disease distribution or the vector distribution and the environmental variables, GIS can lead to an understanding of which factors control the distribution of a disease. Once the environmental factors are understood, GIS can be used to create maps of areas for spraying or other preventive measures. Targeted prevention programs save limited resources and are particularly helpful for poor countries.

The Laboratory for Terrestrial Physics is participating in several research projects to study the environmental determinants of vector-borne diseases. Projects include: 1) using remote sensing to estimate the area of mosquito larval habitat in Korea for calculating the cost of control programs, 2) determining the distribution and land cover types associated with Bartonellosis in Peru, 3) using remote sensing and GIS to study the marshes, rivers and other environmental determinants of malaria in Belize, and 4) relating the distribution of malaria and mosquitoes in Thailand to remotely sensed environmental factors. This research is being done in collaboration with the Center for Application of Remote Sensing and GIS in Public Health at the Uniformed Services University of the Health Sciences (USUHS) in Bethesda, Maryland, the U.S. Army, the University of California, Geo Eco Arc Research, the Peruvian Ministry of Health, and the Belizean Ministry of Health.

**Remote Sensing for Malaria Prevention in Korea**

After being absent from the Republic of Korea since the 1970's, malaria (Plasmodium vivax) re-emerged with the occurrence of 2 cases in 1993. The number of cases has increased almost every year since. The focus of the disease has been just south of the Demilitarized Zone (DMZ) between the Republic of Korea (ROK) and the People's Democratic Republic of Korea (PDRK). From 1993 through December 2000, more than 3,700 cases of malaria were confirmed with more than 1% of the cases occurring in U.S. military personnel stationed in the Republic of Korea (Preventive Services Directorate, 18th Medical Command, Seoul, ROK; personal communication).

US Army personnel stationed near the Demilitarized Zone (DMZ) currently use chemoprophylactic drugs and other preventive measures such as insecticide-impregnated bednets and topical repellents. The use of larvicides in the rice paddies and ponds surrounding the military bases is another option. The purpose of this study was to estimate the area covered by mosquito habitat using Landsat and IKONOS data for two U.S. military bases in Korea. The area estimates of mosquito habitat are then used to estimate the cost of larviciding near U.S. military bases.

Field work for this project was performed from June through September, 2000, and concentrated on two military bases near the DMZ: Camp Greaves and Camp Casey. Camp Greaves is located in a rural area just south of the DMZ. Camp Casey is approximately 35 miles east of Camp Greaves and is in a more populated area with less agriculture. Standard larval survey techniques, using a plastic dipper in all types of standing fresh water, were done at both sites (Figure 5).

**Figure 5. U.S. military and civilian entomologists, Col. Terry Klein and Dr. Donald Roberts, collecting mosquito larvae in a river near a U.S. military base.**

Seven types of larval habitats were identified and sampled: 1) rice fields, 2) streamside pools 3) irrigation ponds, 4) irrigation ditches, 5) drainage ditches, 6) swamps, and 7) rivers. Irrigation ponds, though small, were found to have high densities of mosquito larvae. Because of the large area covered by rice fields and their proximity to military bases, rice fields are also a very important habitat (Figure 6).

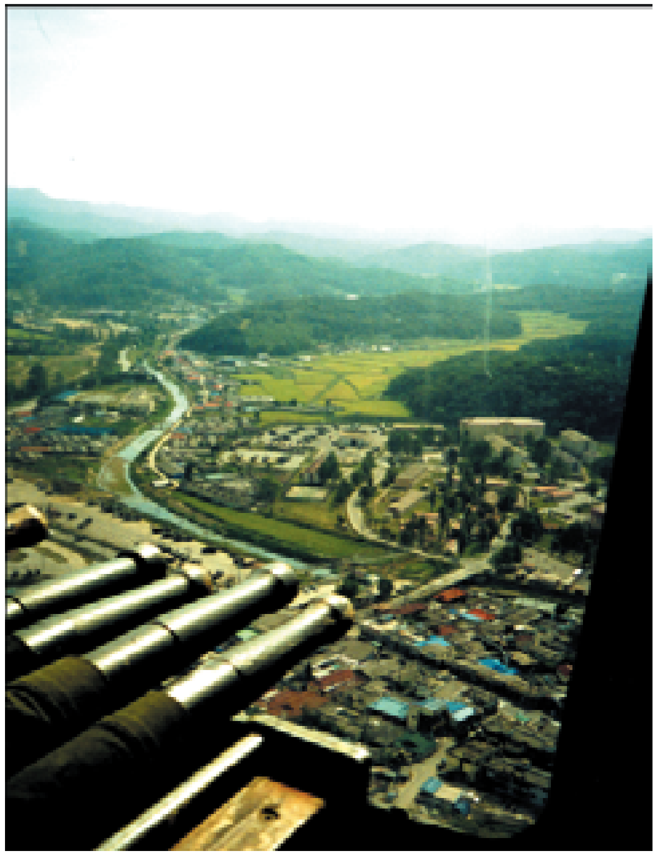

**Figure 6. Photo taken from a medical helicopter over one of the U.S. military bases in South Korea. Military base is in the center of the photo. Notice the rice fields adjacent and behind the base. River next to the base also provides mosquito larval habitat. Poles in the foreground are stretchers, part of the standard equipment on a medical helicopter.**

Two images were used for this study, a Landsat image acquired on April 29, 2000, and an IKONOS image acquired on August 2, 2000. The Landsat image covers both the Camp Greaves and the Camp Casey site. The IKONOS image only covers the Camp Greaves site. The images were georeferenced to a UTM projection and a WGS-84 datum.

A parallelepiped algorithm was used to perform supervised classifications on the IKONOS and Landsat images. For the IKONOS image, training sites were collected for the river, ponds, ditches, and rice fields. Because of the lower resolution, training sites on the Landsat image included only rice fields and the river; ponds, and ditches were too small to be resolved. Other non-habitat areas of the images also were classified as urban and forest, but these were later grouped together as a single, non-habitat class for the purpose of estimating area.

Because of the interest in estimating the amount of larval habitat in areas that would affect the camps, 1-kilometer buffer zones were created around the two camps using Arc/Info software. A program was used to generate reports on the area covered by each class in the classified image. Another program was used to compare the Landsat and IKONOS classifications on a pixel-by-pixel basis and create a new image that depicted matching and non-matching pixels.

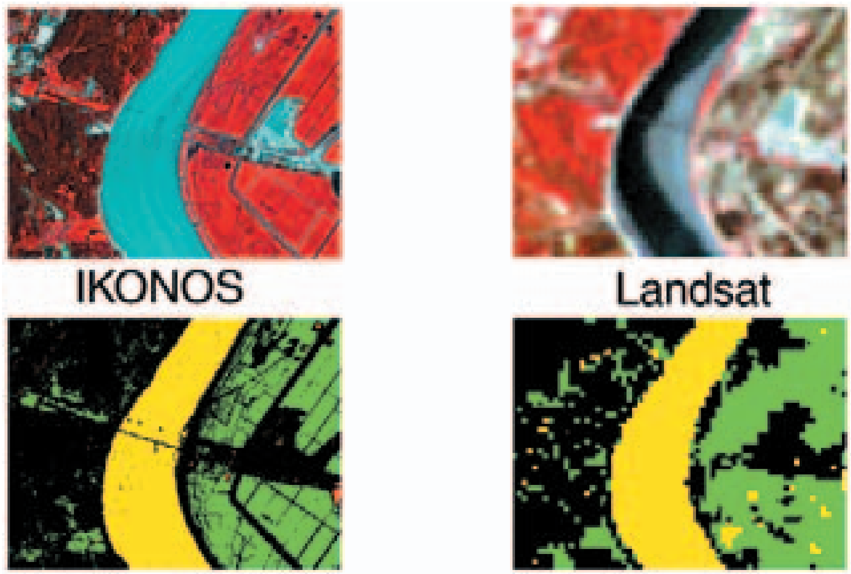


**Figure 7. IKONOS and Landsat images (false color and classified) showing vector habitat and non-habitat areas. The difference in detail is due to the difference in resolution of the two images, IKONOS has 4 meter pixels, Landsat has 30 meter. In the classification, river is shown in yellow, rice fields in green, irrigation ponds in red. Because they are small, irrigation ponds could not be classified on the Landsat image.**

Figure 7 shows the result of the classifications of the Landsat and IKONOS images. Rivers, ponds and rice fields were successfully classified on the IKONOS imagery. Ditches could not be successfully classified on the IKONOS imagery, possibly due to the trees, shrubs and other vegetation that grow along the ditches and make them spectrally similar to other land cover classes. On the Landsat imagery, rivers and rice fields could be classified, but ponds and ditches were too small and could not be used for collecting training sites. A visual comparison of the Landsat and IKONOS classifications, shown in the figure, shows that the two are quite similar in the classification of the river. However, small rice fields, were not as accurately classified on the Landsat classification.

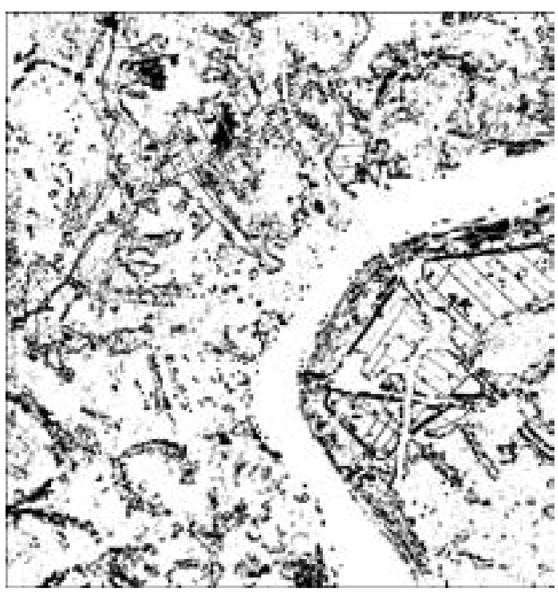

**Figure 8. Result of a pixel-by-pixel comparison of Ikonos and a Landsat classification results. Black pixels (20.63% of the image) represent disagreement in the classifications. White pixels (79.37% of the image) represent agreement. Disagreement mostly due to differences in the resolution and the acquisition dates of the images.**

A comparison of the Landsat and IKONOS classification was done using a program to compare the classifications on a pixel-by-pixel basis. White pixels in Figure 8 represent the pixels that were classified the same on the 2 images; black pixels were classified differently. A 79.37% agreement in classification was found between the Landsat and IKONOS classifications. Differences in the two classifications are due to differences in the acquisition date of the scene and the resolution of the image.

Area estimates for the buffer zone around Camp Greaves are shown in Table 1. Although the difference in the classification of Landsat and IKONOS images was approximately 20%, the area estimates were very close.

**Table 1. Comparison of Land Cover Estimates (m2) for Camp Greaves**

| | Ikonos | Landsat |
|---|---|---|
| Rice fields | 4,198,151 | 4,304,250 |
| Ponds | 48,709 | n/a |

Although similar land cover area estimates of mosquito larval habitat can be obtained from IKONOS and Landsat imagery, the use of IKONOS has the advantage of being able to portray and classify small land cover features such as ponds and rice fields less than 30 by 30 meters in size. Although ponds represent a relatively small portion of the total habitat area, they are an important breeding habitat for mosquitoes since they contain higher larval densities than the rice fields late in the growing season

The habitat land cover estimates were used to estimate the cost of mosquito larviciding around the camps (Table 2). For Camp Greaves, which has fewer soldiers and more habitat area, the cost of chemoprophylaxis is less than the cost of larviciding. For Camp Casey, which has more soldiers and less larval habitat, larviciding world be a cost-effective option. Although cost is not the only consideration, this type of analysis can provide information to help public health officials make decisions.

**Table 2. Cost comparison of chemoprophylaxis to larviciding for control of malaria in South Korea**

| Camp Greaves | Camp Casey |
|---|---|
| 430.4 ha of habitat | 122.5 ha of habitat |
| Larvicide treatment = $40,263.13 | Larvicide treatment = $11,450.37 |
| Chemoprophylaxis = $28,522.80<br>cost for 760 persons | Chemoprophylaxis = $330,264.00<br>cost for 8000 people |

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## Remote Sensing and GIS Studies of Bartonellosis in Peru

Bartonellosis is a bacterial disease endemic to the Andes Mountains that occurs in two phases. In the first phase, fever and anemia can lead to coma and death. If the victim survives the first phase, blood-filled, wart-like skin lesions appear and can last for many months if not treated. Although treatable with modern antibiotics, the disease still claims lives in remote areas without medical care and among those who delay medical care due to inability to pay.

Sand flies have been incriminated as the vectors of bartonellosis. Breeding places of sand flies are difficult to find and are typically under stones, in masonary cracks, in poultry houses or other areas combining darkness, humidity and a supply of organic material for food. Breeding sites are never aquatic. Adult sand flies generally rest in protected situations during the day, but leave these shelters at night to seek a blood meal.

**Figure 9. Study participants being interviewed by a local Peruvian nurse as part of the bartonellosis study in Caraz, Peru.**

A study of the disease led by USUHS has been on-going for the last 5 years and includes medical, epidemiological, entomology, and animal studies (Figure 9). The Laboratory for Terrestrial Physics has participated as part of this larger investigation by contributing remote sensing and mapping. Remotely sensed images are used to map houses in the study area. Maps of houses are important to the field teams since there are no large-scale maps of the area. Maps and satellite images are used to determine the distribution of the disease and the environmental factors that may influence the abundance and distribution of sand flies.

Several conclusions have been drawn from the remote sensing work to-date. Bartonellosis has been found to occur primarily in agricultural areas. The incidence of disease is low in urban areas. The disease does not occur more frequently near rivers. The disease tends to occur in clusters (Figure 10) perhaps due to what is now thought to be the mechanism of the spread of the disease, person to sand fly to person, with no intermediate host.

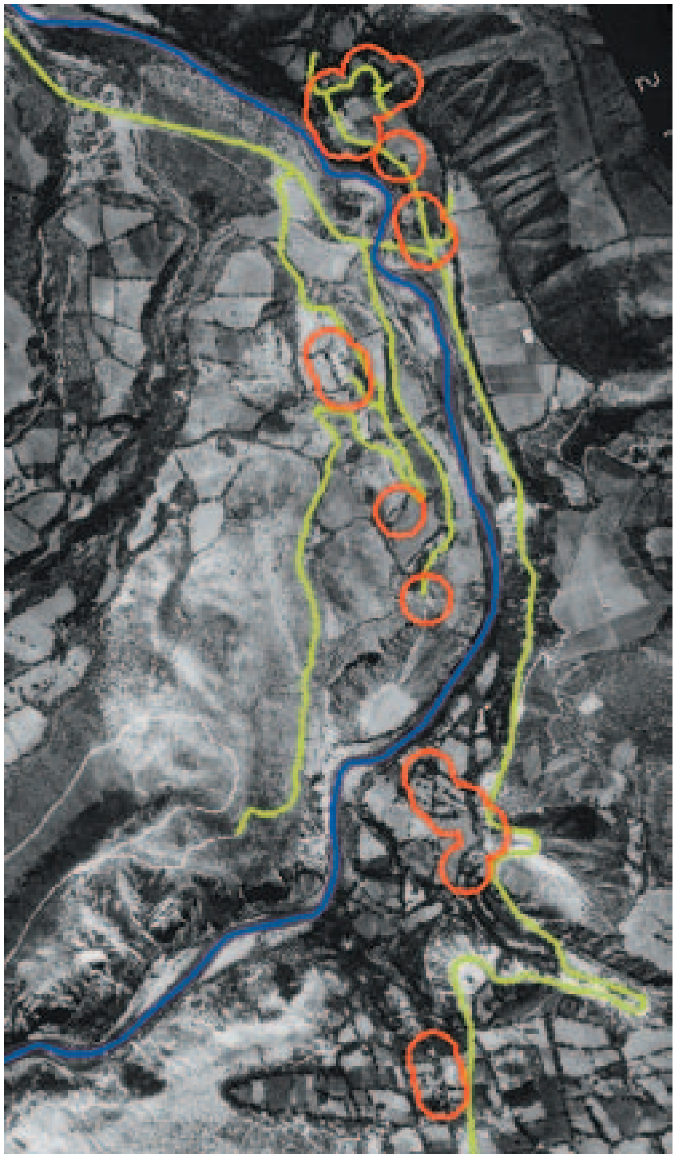

**Figure 10. Aerial photograph of a village in the Andes Mountains of Peru. Red lines represent 60-meter buffer zones around houses testing positive for cases of bartonellosis. Notice the clustering of cases. Blue line is the river. Green lines are roads. This image was created by Judith Chamberlin, a student in a course taught by the LTP at the Uniformed Services University of the Health Sciences.**

We are currently testing the idea that the distribution of the disease might be determined within the agricultural areas by land cover type. A preliminary examination of positive and negative case houses with a Landsat unsupervised classification showed an association of positive case houses with one agricultural land cover class in the Caraz area. However, no association was apparent using high resolution IKONOS images for the Cusco area. The Caraz study will be redone using a high resolution IKONOS satellite image and additional disease data, recently collected.

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**Environmental Determinants of Malaria in Belize**

This project studies how human-induced change in Belize and natural factors affect the breeding habitats of mosquitoes and the distribution of malaria. Malaria is an on-going problem in Belize, a small country in Central America. Projects which improve the understanding of the distribution of malaria in Belize, benefit the country by allowing it to allocate scarce resources for malaria control in the areas that will benefit the most. Understanding if human-induced land cover change affects mosquito populations, may be an important factor in malaria prevention in this country.

Three main hypotheses are being tested:

1) Increased phosphorus from the runoff from agricultural land into the marshes increases the amount of tall dense macrophytes (cattails) which serve as a breeding habitat for the most efficient malaria vector species in Belize.

2) The distribution and incidence of malaria within the villages of Belize is influenced by weather, land cover including water bodies and vegetation type, and topography.

3) Removal of forest along streams allows the growth of bamboo that provides more vector habitat in the form of floating debris in the streams.

*Hypothesis 1: Phosphorus from the runoff from agricultural land into the marshes increases the amount of tall dense macrophytes.*

In order to map the distribution of tall dense macrophytes (TDM) and the surrounding land cover of the marshes, SPOT images and Radarsat images were acquired and coregistered to 1:50,000 scale topographic maps. Kevin Pope (Geo Eco Arc Research) processed the SPOT and Radarsat images to create a classification map showing the marshes, the TDM, and other land cover (Figure 11). It was found that while SPOT imagery was and excellent source of data for classifying the marshes overall, only Radarsat was able to identify the TDM marsh due to the corner reflector characteristics exhibited by the TDM. After trying several processing methods, it was found that a simple threshold algorithm is the most useful for extracting the higher reflectance TDM marshes from the Radarsat image. A number of TDM marsh locations mapped by Radarsat were verified in the field in April.

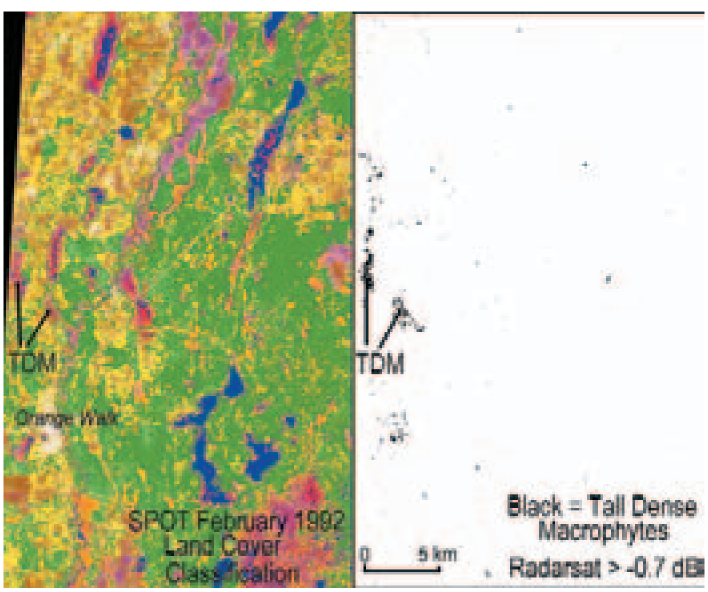


**Figure 11. SPOT land cover classification (left) created using an isodata unsupervised classification program and radarsat image (right) processed using a threshold algorithm. Although tall dense macrophytes (TDM), or cattail marsh, could not be classified separately on the SPOT image, the high radar return allows it to be mapped on the radar image. On the SPOT classification, blue=water, red=low marsh, purple=medium marsh, pink=high marsh, green=forest, yellow-brown-orange=agriculture, white=urban or bare ground. Processing by Kevin Pope, Geo Eco Arc Research.**

In order to select marshes for transect sampling and to determine the spatial relationship between TDM marshes and land use, further analysis was done by the LTP on the classification maps. A separate image was made containing only the marsh pixels from the classification. The marsh image was then filtered using a 7 by 7 mode filter to remove the noise and the very small marshes from the image. Seventy-seven marshes were selected to be used for further processing and as possible transect sites in the field. The 77 marshes all contained TDM and included both marshes surrounded by agricultural fields ("impacted marsh") and marshes that were completely surrounded by forest ("pristine marsh").

To create a report of the land cover types for the 77 marshes, further processing was necessary. The filtered marsh image was converted to a vector format. Each marsh was extracted into a separate vector segment and buffered 12.5 meters outside of the marsh. A report was created for each marsh and its surrounding buffer zone that listed the square meters of each land cover type for the marsh. The data were entered into a spreadsheet program and the percent of agriculture, forest and TDM for each marsh was calculated. In order to compare the amount of TDM for "pristine" and "impacted" marshes, the percent agriculture and forest versus the amount of TDM was plotted. There was no correlation between the amount of TDM and the surrounding land cover type.

The lack of correlation between the amount of TDM and the presence or absence of agriculture seems to disprove the hypothesis that increased phosphorus from agriculture promotes the growth of TDM. However, we have not yet examined marshes without TDM. There may be a correlation between the presence versus absence of TDM with agriculture. This possibility will be examined in the coming year.

*Hypothesis 2: The distribution and incidence of malaria within the villages of Belize is influenced by weather, land cover including water bodies and vegetation type, and topography.*

A national GIS is being developed by Shilpa Hakre, a USUHS graduate student, with help and advice from Penny Masuoka and Andrew Au. The purpose of the GIS is to study habitat distribution, land cover, weather, topography and malaria incidence on a regional scale. GIS data of rivers and settlements (villages) were obtained from the Belize Land Information Centre (LIC). The settlement data have been combined with information from the Belize national malaria data base and the national census to create a GIS of malaria incidence for 150 villages. Maps of the spatial distribution of malaria incidence from this GIS show that malaria incidence increases in southern Belize.

River data obtained from the LIC are being processed with other data in the national GIS in a couple of ways. A program was run to give the distance from each village to the nearest river. These data will be analyzed with the mean malaria incidence for each village to determine the relationship between the two. The total length of streams within a buffer around each village will also be analyzed.

A Landsat mosaic of Belize and a vegetation map are being used to obtain the land cover types for each village. A 1-km digital elevation model was downloaded from the internet and slope was calculated for the country. A value for slope and elevation will be extracted for each village.

Since weather events can affect malaria incidence, a retrospective study of the weather in Belize is also being done. A graph of the malaria incidence data on a month-by-month basis, showed that the incidence of malaria increases for some districts during the rainy season. To further explore this relationship, we have obtained temperature and precipitation data for 20 weather stations in Belize. These will be put into the GIS and interpolated to obtain raster images of precipitation and temperature. The weather data will be added to the national GIS and compared to the malaria incidence for villages.

*Hypothesis 3: Removal of forest along streams allows the growth of bamboo that provides more vector habitat in the form of floating debris in the streams.*

Bamboo leaves form mats of floating debris and create protected breeding habitats. This hypothesis is being tested by a USUHS graduate student, Nicole Achee, as part of her dissertation with help and advice from Penny Masuoka. Nicole is currently sampling mosquito larvae along the Belize river in stretches of bamboo, forest and other land cover types. The SPOT images are being used to map the location of agricultural lands and forest along the Belize river in order to predict areas of bamboo growth. It is believed that bamboo growing along this river is not wide enough to map with the SPOT data which has 20 meter pixels.

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**Remote Sensing and GIS Studies of Malaria in Thailand**

This new project uses remote sensing and GIS techniques to analyze field data collected by a larger, established project entitled "Mosquito Acquisition of Malaria (MaM): Role of host and vector factors as determinants of mosquito infection." Dr. Russell Coleman, US Army, Thailand, is the principal investigator for the larger project. The MAM project is a 3-4 year prospective study of approximately 480 individuals living in Ban Kong Mong Tha, Tambon Laivou, Kanchanaburi Province, Thailand. The study started in January, 2000 and will end no-later-than December, 2003. Monthly fingerpricks of villagers are evaluated for malaria. Monthly collection of adult mosquitoes and larvae will allow seasonal and geographic distributions to be determined. Blood-engorged mosquitoes are collected throughout the village and the blood meal is subjected to DNA analysis. Using the DNA fingerprint obtained from each person in the village, the specific individuals who mosquitoes are feeding on will be determined.

The overall goal for the remote sensing/GIS studies is to use geographic information systems technology and remote sensing resources to research and define spatial relationships and the environmental, vector (mosquito) and host (human) roles of disease transmission and malaria incidence within the study village, Ban Kong Mong Tha. There are three main hypotheses: 1) The spatial distribution of malaria cases, is clustered so that the majority of cases occurs within a minority of houses. 2) The majority of mosquitoes stay within a short distance (<500m) of their last blood meal. 3) Environmental factors, such as proximity to water bodies and surrounding vegetation, determine the spatial distribution and density of mosquitoes and affect the distribution of malaria incidence within the village.

*Hypothesis 1: The spatial distribution of malaria cases within the village of Ban Kong Mong Tha is clustered so that the majority of cases occurs within a minority of houses.*

If malaria cases are spatially clustered, control programs can be planned to target the high malaria incidence houses to have a maximum impact with a minimum effort. Previous work in Belize found this spatial clustering of malaria cases, however, it is important to test this relationship, in other areas with other vectors. The Thailand site is an excellent study site not only because of the different vectors, but also because of the "closed" nature of the village (its inaccessibility gives few opportunities for movement in and out of the village).

Using data collected by the MaM Project, a GIS database is being constructed that contains house locations with attributes for each house including information such as the number of residents in the house, the number of malaria cases, and so forth. Maps will be created from the GIS data base.

*Hypothesis 2: The majority of mosquitoes stay within a short distance (<500m) of their last blood meal.*

If the clustering of malaria cases is shown to be true, the clustering may be caused by mosquitoes staying close to or returning to their original blood meal site. This hypothesis is important to test since there is currently a limited understanding of why malaria cases tend to be clustered.

The location of the mosquitoes' blood meals will be possible because the MaM Project will develop a DNA fingerprint for each individual in the study village. Blood-fed mosquitoes will be identified as to the source of their blood meal by testing the DNA in each bloodmeal. The distance from blood meal to capture location can be determined by creating a map with lines having endpoints representing the location of the blood meal and the capture location.

*Hypothesis 3: Environmental factors, such as proximity to water bodies and surrounding vegetation, determine the spatial distribution and density of mosquitoes and affect the distribution of malaria incidence within the village.*

Clustering of cases within a small number of houses may be explained by environmental factors such as land use/land cover close to the house. A variety of types and scales of satellite data including 30-meter Landsat Enhanced Thematic Mapper + (ETM+) images, 4-meter IKONOS satellite images, and Radarsat images are being used for this project. Landsat and Radarsat provide an overview of the area and the location of major land cover classes within the area. Because of the scale of the project, and the need to know the land cover around individual houses, IKONOS imagery will be the most important remote sensing data set for this project and has been requested.

If the distance between blood meal and capture location for mosquitoes is low, buffer zones will be drawn around each house. The size of the buffer zone will be determined by average distance from blood meal to capture. The buffer zones will be used to create a report on the amount of each land cover type within each buffer zone. Alternatively, if the distance between blood meal and capture location is high, the distance to the nearest mosquito breeding habitat for each house will be determined.

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## 2001 Refereed Publications

The Laboratory's publications for the year 2001 are listed in the various discipline sections. The total number of our refereed publications that actually appeared in print in 2001 was 114 (i.e., this does not include papers that were "accepted" and/or "in press"). This figure includes refereed journal articles, book chapters, and/or books authored by our civil servants, post doc's, visiting scientists, contractors, and people from other agencies co-located in our physical space who conduct joint research with us. The 7 publications in Terrestrial Information Systems are listed below.

Noll, C. and M. Dube, "The Crustal Dynamics Data Information System CDDIS -- NASA's Space Geodesy Data Archive", at Science Data Centers Symposium, Pasadena, CA, March 2001.

Noll, C. and M. Dube, "The IGS Global Data Center at the CDDIS - an update", Physics and Chemistry of the Earth (26A)6-8, pp 603-604, Elsevier Science Ltd, 2001.

Noll, C., "Current Status of and Backup Plans for Flow of IGS Data and Products", Physics and Chemistry of the Earth (26A)6-8, pp 595-601, Elsevier Science Ltd, 2001.

Tavernier G., et.al., "International DORIS Service on Web", EOS Transactions, American Geophysical Union, December 2001.

Vermote, E., Justice, C., Descloitres, J., El Saleous, N., Roy, D., Ray, J., Margerin, B., Gonzalez, L., A., "SeaWiFS global monthly coarse-resolution reflectance data set, International Journal of Remote Sensing", 22:1151-1158, 2001

Vermote EF, Justice CO, Descloitres J, El Saleous N, Roy DP, Ray J, Margerin B, Gonzalez L, 2001, A SeaWiFS global monthly coarse-resolution reflectance dataset, INTERNATIONAL JOURNAL OF REMOTE SENSING, 22: (6) 1151-1158 APR 2001

Wang YJ, Tian YH, Zhang Y, El Saleous N, Knyazikhin Y, Vermote E, Myneni RB, 2001, Investigation of product accuracy as a function of input and model uncertainties - Case study with SeaWiFS and MODIS LAI/FPAR algorithm, REMOTE SENSING OF ENVIRONMENT, 78: (3) 299-313 DEC 2001

## 2001 Conference Proceedings

Korontzi, S., Justice C., Shugart H., Roy D., Dowty P., HéLy, C., Alleaume, S., SAPYRO: A spatiotemporal model for estimating pyrogenic emissions from vegetation fires in southern Africa, American Geophysical Union Fall 2000 Meeting, Session A09, San Fransisco CA, December 10-14 2001.

Roy, D.P., Justice, C. O., Giglio, L., Petitcolin, F., Vermote, E ., Morisette, J ., 2001, The Moderate Resolution Imaging Spectroradiometer (MODIS) fire products and SAFARI 2000: mapping and validation of regional biomass burning, Invited Presentation at American Geophysical Union Fall 2000 Meeting, Session A09, San Fransisco CA, December 10-14 2001.

Tacheba, B., P. O. Dube, D. Roy, C. O. Justice, K. Muhwandagara, S. Makungwa, P. Frost, K. Gumbo, J. Leroux, P. Mushove and T. Landmann, 2001, Southern Africa Fire Network (SAFNet) of the Global Observation of Forestry Cover (GOFC): Developing Capacity for Operational Fire Monitoring and Management Systems in Southern Africa. 5th AFRICAGIS Conference and Exhibition, 5-9 November 2001, Nairobi, Kenya.

## 2001 Presentations & Seminars

Andre, R., R. Fernandez, P. Masuoka, N. Solozano, D. Roberts, P. Lawyer, M. Zyzak, J. Chamberlin, and E. Rejmankova, 2001. Population Dynamics of Lutzomyia Verrucarum around Bartonella Case and Non-case houses in Caraz, Peru. USUHS Research Day, 2001.

Claborn, D., P. Masuoka, and R. Andre, 2001. Remote sensing of malaria vector habitat in Korea. U. S. Army's Force Health Protection Conference. Santa Fe, NM. 25-30 August, 2001.

Claborn, D., P. Masuoka, R. Andre, T. Klein, and S. Gordon, 2001. Remote sensing and GIS as decision making tools for control of malaria in South Korea. Triservice Entomological Conference, Jacksonville, FL. 25 Feb-3 March, 2001.

Claborn, D., P. Masuoka, R. Andre, T. Klein, and S. Gordon, 2001. Remote sensing and GIS as decision making tools for control of malaria in South Korea. American Public health Association, Atlanta GA, 29-30th Oct, 2001.

Descloitres, J., L. Giglio, R. Sohlberg, J. Owens, C. Justice, J. Townshend, J. Seaton, M. Crisologo, M. Carroll, and M. Finco, 2001: The MODIS Land Rapid Response Project: A Comprehensive Suite of Products to Support U.S.D.A. Forest Service Fire Management. Presented at the American Geophysical Union Fall Meeting, San Francisco.

Masuoka, P., D. Claborn and R. Andre, 2001. Use of IKONOS and Landsat to estimate mosquito habitat for malaria control in South Korea. High Spatial Resolution Commercial Satellite Imaging Workshop, 19-21 March 2001, Greenbelt MD.

Roy D., Borak, J., Devadiga, S., Zheng, M., Wolfe,R.,"MODIS LAND QA First Year Review & (some) Lessons Learned", NASA Earth Observing System QA Working Group Meeting, March 27-28 2001, Boulder, Colorado.

Roy, D., Frost, P., Justice, C., Landmann, Mhwandagara, K., Mkosana, F., Pereira, J., Le Roux, J., Tacheba, B., Zacharias, A.,"SAFARI 2000 MODIS Burned Area Validation Overview", GOFC-Fire Satellite Product Validation Workshop, Lisbon, Portugal, 9 - 11 July 2001.

Roy, D.P .,"A Regional MODIS Burned Area Map of Southern Africa", SAFARI 2000 First Data Workshop, Siavonga, Zambia, August 28 - 31, 2001.

Roy, D.P., "Burned area mapping in southern Africa: case study synthesis and regional application of MODIS data", Land Cover Land Use Change Science Team Meeting, University of Maryland, Nov 19-21, 2001.